

# Cosmic Natural Selection

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## Abstract

I make a number of comments about Smolin's theory of Cosmic Natural Selection.

In an unpublished note I criticized Smolin's theory of cosmological natural selection [1] which argues that we live in the fittest of all possible universes. By fitness, Smolin means the ability to reproduce. In my criticism I used the example of eternal inflation which is an extremely efficient reproduction mechanism. If Smolin's logic is applied to that example it would lead to the prediction that we live in the universe with the maximum cosmological constant. This is clearly not so.

Smolin proposes that the true mechanism for reproduction is a bouncing black hole singularity that leads to a new universe behind the horizon of every black hole. Thus Smolin suggests that the laws of nature are determined by maximizing the number of black holes in a universe.

Smolin also argues that it is not obviously wrong that our physical parameters, including the smallness of the cosmological constant, maximize the black hole formation. To make sense of this idea, one must assume that there is a very dense discretuum of possibilities, in other words a rich landscape of the kind that string theory suggests [4][5][6][7].

The detailed astrophysics that goes into Smolin's estimates is extremely complicated—too complicated for me—but the basic theoretical assumptions that go into the theory can be evaluated, especially in light of what string theory has taught us about the landscape and about black holes.

As I said, there are two mechanisms, eternal inflation and black hole production that can contribute to reproduction, and it is important for Smolin's scenario that black holes dominate. Considering the low density of black holes in our universe and the incredible efficiency of exponential inflation, it seems very hard to believe that black holes win unless eternal inflation is not possible for some reason.

Smolin's argues that we know almost nothing about eternal inflation but we know a great deal about black holes including the fact that they really exist. This is a bit disingenuous. Despite a great deal of serious effort [8] [9], the thing we understand least is the resolution of black hole and cosmic singularities. By contrast, eternal inflation in a false vacuum is based only on classical gravity and semiclassical Coleman de Luccia bubble nucleation [2][3].

The issue here is not whether the usual phenomenological inflation was of the eternal kind although that is relevant. Eternal inflation taking place in any false vacuum minimum on the landscape would favor (in Smolin's sense) the maximum cosmological constant. But for the sake of argument I will agree to ignore eternal inflation as a reproduction mechanism.

The question of how many black holes are formed is somewhat ambiguous. What if two black holes coalesce to form a single one. Does that count as one black hole or two? Strictly speaking, given that black holes are defined by the global geometry, it is only one black hole. What happens if all the stars in the galaxy eventually fall into the central black hole? That severely diminishes the counting. So we better assume that the bigger the black hole, the more babies it will have. Perhaps one huge black hole spawns more offspring than  $10^{22}$  stellar black holes.

That raises the question of what exactly is a black hole? One of the deepest lessons that we have learned over the past decade is that there is no fundamental difference between elementary particles and black holes. As repeatedly emphasized by 't Hooft [10][11][12], black holes are the natural extension of the elementary particle spectrum. This is especially clear in string theory where black holes are simply highly excited string states. Does that mean that we should count every particle as a black hole?

Smolin's theory requires not only that black hole singularities bounce but that the parameters such as the cosmological constant suffer only very small changes at the bounce. This I find not credible for a number of reasons. The discretuum of string theory does indeed allow a very dense spectrum of cosmological constants but neighboring vacua on the landscape do not generally have close values of the vacuum energy. A valley is typically surrounded by high mountains, and neighboring valleys are not expected to have similar energies.

Next—the energy density at the bounce is presumably Planckian. Supposing that a bounce makes sense, the new universe starts with Planckian energy density. On the other hand Smolin wants the final value of the vacuum energy density to be very close to the original. It sounds to me like rolling a bowling ball up to the top of a very high mountain and expecting it to roll down, not to the original valley, but to one out of  $10^{120}$  with almost identical energy. I find that unlikely.

Finally, we have learned some things about black holes over the last decade that even Stephen Hawking agrees with [13]. Black holes do not lose information. The implication [14] is that if there is any kind of universe creation in the interior of the black hole, the quantum state of the offspring is completely unique and can have no memory of the initial state. That would preclude the kind of slow mutation rate envisioned by Smolin.

Smolin seems to think that there is significant evidence that singularity resolution (by bounce) is imminent. Loop quantum gravity, according to him, is on the threshold of accomplishing this. Perhaps it will. But either it will be consistent with information

conservation in which case the baby can have no memory of the parent, or it will not. If not it probably means that Loop gravity is inconsistent.

## References

- [1] Lee smolin, Scientific Alternatives to the Anthropic Principle, hep-th/0407213
- [2] S. R. Coleman and F. De Luccia, Phys. Rev. D **21**, 3305 (1980).
- [3] S. K. Blau, E. I. Guendelman and A. H. Guth, “The Dynamics Of False Vacuum Bubbles,” Phys. Rev. D **35**, 1747 (1987).
- [4] Raphael Bousso, Joseph Polchinski, Quantization of Four-form Fluxes and Dynamical Neutralization of the Cosmological Constant, hep-th/0004134, JHEP 0006 (2000) 006
- [5] Shamit Kachru, Renata Kallosh, Andrei Linde, Sandip P. Trivedi, de Sitter Vacua in String Theory, hep-th/0301240
- [6] Leonard Susskind, The Anthropic Landscape of String Theory, hep-th/0302219
- [7] Michael R. Douglas, The statistics of string/M vacua, hep-th/0303194, JHEP 0305 (2003) 046  
Sujay Ashok, Michael R. Douglas, Counting Flux Vacua, hep-th/0307049  
Michael R. Douglas, Bernard Shiffman, Steve Zelditch, Critical points and supersymmetric vacua math.CV/0402326
- [8] G. T. Horowitz and J. Polchinski, Phys. Rev. D **66**, 103512 (2002) [arXiv:hep-th/0206228].
- [9] L. Fidkowski, V. Hubeny, M. Kleban and S. Shenker, “The black hole singularity in AdS/CFT,” JHEP **0402**, 014 (2004) [arXiv:hep-th/0306170].
- [10] G. 't Hooft, “The unification of black holes with ordinary matter,” *Prepared for Les Houches Summer School on Gravitation and Quantizations, Session 57, Les Houches, France, 5 Jul - 1 Aug 1992*
- [11] L. Susskind, “Some speculations about black hole entropy in string theory,” arXiv:hep-th/9309145.

- [12] G. T. Horowitz and J. Polchinski, “A correspondence principle for black holes and strings,” *Phys. Rev. D* **55**, 6189 (1997) [arXiv:hep-th/9612146].
  - [13] New York Times 7/22/04
  - [14] G. T. Horowitz and J. Maldacena, “The black hole final state,” *JHEP* **0402**, 008 (2004) [arXiv:hep-th/0310281].
- A. Guth and L. Susskind, To be published